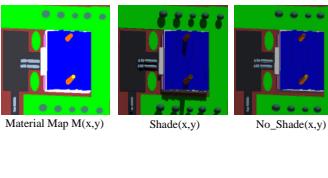


1. Introduction
2. Synthetic Hypercube Generation
 - (a) Geometry Model
 - (b) Spectral Model for Surfaces
 - (c) Thermal Model
 - i. Statistical Model
 - ii. Finite-Difference Model
 - (d) Gas Plume Simulation
 - (e) Atmospheric Model
 - (f) Data-cube Generation
3. Temperature-Emissivity Separation (TES) Algorithm
4. Conclusions

Material, Illumination and Shadow Maps



(b) Finite-Difference Model

The energy balance equations states that:

$$Q_{rad} + Q_{wind} + Q_{air} = E_{solar},$$

where for the n-th time-step:

$$Q_{wind} = h_a \cdot u \cdot \Delta t \cdot A \cdot (T_{air,n} - T_{air,n-1}),$$

$$Q_{air} = \frac{T_{air,n} - T_{air,n-1}}{\Delta t},$$

and

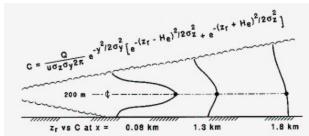
$$E_{solar(n+1)} = P_{solar} \cdot \frac{\Delta z}{\Delta t} \cdot T_{air,n} - T_{air,n}$$

The temperature of the layer below the surface is given by:

$$T_{air,n+1} = T_{air,n} + \frac{2h_a}{\sigma} \frac{\Delta t}{\Delta z} \exp(-\frac{2k}{\sigma} \Delta z) \cdot erfc(\frac{\Delta z}{\sqrt{4h_a \Delta t}}),$$

where $q_{wind} = h_a \cdot u \cdot \Delta t$, $\sigma = 5.67 \cdot 10^{-8} W/m^2 K^{4.5}$ is the Stefan-Boltzmann constant, $h_a = 16.786$ for a turbulent flow, h_a is the wind speed in m/s, $\alpha = k/(C_p)$ is the thermal diffusivity in m^2/s , $erfc(x) = 1 - erf(x)$ is the complementary error function, k is the thermal conductivity in W/mK , ρ is the density in kg/m^3 , C_p is the specific heat in $J/(kg K)$, ϵ is the emissivity in $[0,1]$ and thermal ($x = T$), Δt is the time step in s and Δz is the layer thickness in m.

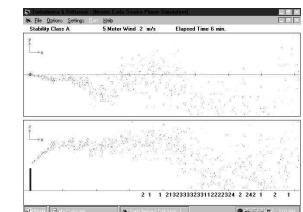
(b) Gaussian Plume Model, e.g. Beychok, 1994



Disadvantage: Represents a long-time average of gas concentration

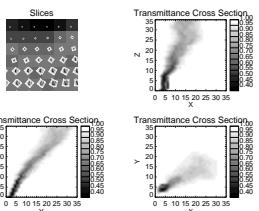
GAS PLUME SIMULATION

(a) Monte Carlo Model by Blackadar, 1997



Disadvantage: Difficult to produce gas concentration maps.

Plume Slices



Time sequence of horizontal plume slices demonstrating wind effects, diffusion (scale), plume rotation and changing fractal dimensions (UL).

DATA-CUBE GENERATION

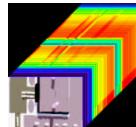
$L_{total}(x, y, \lambda) = L_{ground}(x, y, \lambda) + L_{gas}(x, y, \lambda) + L_{plume}(x, y, \lambda) + L_{reflected}(x, y, \lambda)$, where

$$L_{ground}(x, y, \lambda) = \varepsilon(x, y, \lambda) B(\lambda, T_{ground}(x, y)) T_{gas}(x, y, \lambda) \tau_{gas}(x, y, \lambda),$$

$$L_{gas}(x, y, \lambda) = [1 - \tau_{gas}(x, y, \lambda)] B(\lambda, T_{gas}(x, y, \lambda)) \tau_{gas}(x, y, \lambda),$$

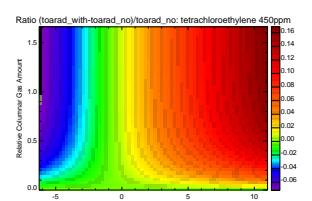
$$L_{reflected}(x, y, \lambda) = L_{plume}(x, y, \lambda) = [\varepsilon(x, y, \lambda) T_{plume}(x, y, \lambda) \tau_{plume}(x, y, \lambda)],$$

$$\text{and } B(\lambda, T) \text{ is the Planck function describing the spectral radiance in } [W/cm^2 ster \mu m].$$



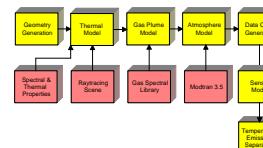
Simulated thermal hypercube with sample spectrum.

Effect of temperature difference between background and plume



(On - Plume - Off - plume)/(Off - Plume) ratio for TCE

Synthetic Hypercube Generation



GEOMETRY MODEL



THERMAL MODEL

(a) Statistical Model

P. Jacobs measured grass, concrete, soil and trees for 3 time periods. Mean temperature and RMSE values are listed for day and night times.

Steps:

1. Calculate normalize computed diurnal cycles of solar irradiance.
2. Assign each surface a time constant to simulate heat storage.
3. Compute the ground temperature at image coordinates x and y and $T_{plume}(x, y, n)$ at time n :

$$T_{plume}(x, y, n) = A + B \frac{N}{S} \cdot Shade[x, y, n - i] \exp[-\alpha(M[x, y])|n - i|],$$

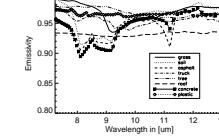
where A and B are constants determined so that the temperature history agrees with the statistically measured temperature range and $\alpha(M[x, y])$ is the material property dependent time constants.

SPECTRAL MODEL FOR SURFACES

IR Databases:

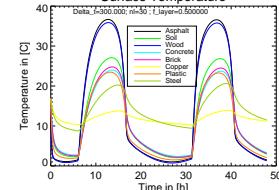
1. Non-conventional Exploitation Factors Data Systems (NEFDs) (cicks.ohiostate.edu/nefd/nefdome.htm)
2. Salisbury and D'Aria, 1992 (aster.jpl.nasa.gov)

Material Emissivities



Example: wind speed was 4 m/s, the air temperature 5 deg C, the irradiance was set for Julian day 88 and a latitude of 34 deg

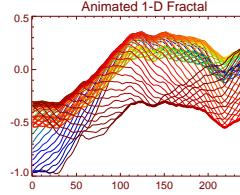
Surface Temperature



Surface temperatures for two diurnal cycles for eight materials.

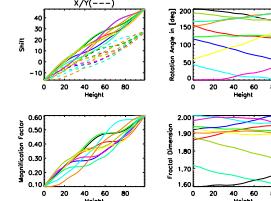
(c) FRACTAL PLUME GENERATION

1-D Fractal



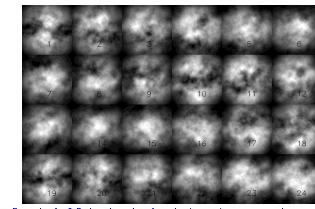
Example of a 1-D time-dependent fractal - the curves are shaded according to the time variable

Multi-fractal Plume Variables



Plume variables: x and y shift (UL), rotation angle (UR), magnification (LL) and fractal dimension (LR).

2-D Fractal Generation

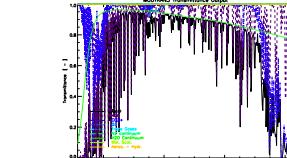


Example of a 2-D time-dependent fractal - the numbers represent time samples

ATMOSPHERIC MODEL

MODTRAN 3 (www.phys.ohio.edu/mil/VSRM/proc/modtran.htm)

MODO a GUI (http://geo.snsr.nist.gov/pub/dclabsp/Mod_0.0.1.html)



Example of a MODTRAN output showing atmospheric transmission

GAS SPECTRAL LIBRARIES

EPA's Emission Measurement Center

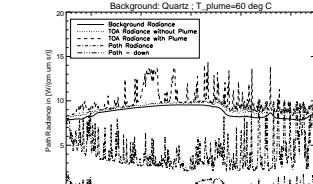
(15, 67, 104, 128, lm/cm²/nm/cm²/sr/fir/cm)

- 1 cm⁻¹ resolution
- 405 measurements of about 180 different gases
- Free-path length measurements of gases at several temperatures

Galactic Industries Web site (www.giic.com)

- EPA FT-IR Vapour Phase Library (3276 gases at 4 cm⁻¹ sampling)
- David Sullivan FT-IR Library
- ...

Background: Quartz : $T_{plume}=60$ deg C



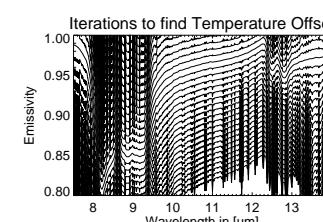
Mixture of 60 deg C gases (500 ppm Ammonia and 500 ppm trichloroethylene)

Radance computed over quartz surface at 32 deg C.

Conclusions

Hyperspectral cubes simulation includes:

- Realistic temperature distributions,
- Material dependent emissivities,
- Complex time-varying gas plumes, and
- Atmospheric absorption and emission.
- Study effects of spectral/spatial resolution, calibrations, SNR
- Future Work
 - Include detailed sensor simulation,
 - Add hyperspectral textures,
 - Handle mixed pixels, and
 - Perform detailed TES analysis for various sensors.



Retrieved emissivity as a function of temperature offset θ^*